The Ordovician-Silurian Stratigraphy of the Cudgegong-Mudgee District, New South Wales

JOHN W. PEMBERTON

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Ordovician and Silurian rocks of the Cudgegong-Mudgee district crop out in a narrow belt separating Devonian sequences on the northern Capertee High.

The basal unit consists of Late Ordovician basaltic and andesitic lava and their fragmental equivalents (*Cudgegong Volcanics*) which are unconformably overlain by a thick Wenlockian to Ludlovian sequence of shallow marine to emergent units. The lowermost *Willow Glen Formation* (fossiliferous clastic sediments and limestone) was deposited in a coastal environment affected by a series of transgressive/regressive cycles. It is overlain by a thick and persistent sequence of dacite lava and breccia (*Windamere Volcanics*) with associated mass flow detritus (*Toolamanang Formation*), followed by volcanic quiescence with continuing shallow marine sedimentation (*Millsville Formation*).

The Ordovician-Silurian rocks occupy the core of a shallowly plunging northwest-trending anticline, the northeast limb of which is overturned. The rocks of this belt are disconformably overlain by Early Devonian units, a continuation of shallow marine conditions on the northern Capertee High, whereas the fluviatile Late Devonian Lambie Group overlies the strata with slight angular unconformity.

J. W. Pemberton, Department of Geology, University of Wollongong, P.O. Box 1144, Wollongong, Australia. 2500; *manuscript received 12 July 1988, accepted for publication 19 April 1989.*

LOCATION

Mudgee is 260km northwest of Sydney in the central tablelands of New South Wales (Fig. 1). The village of Cudgegong, 35km to the southeast, and surrounding properties have been resumed by the Water Resources Commission as part of the Windamere Dam and Recreation Park, along the Cudgegong River valley. Consequently, parts of the study area including Cudgegong township have, since 1984, been flooded by the infilling Windamere Dam.

GEOLOGICAL SETTING

The Cudgegong-Mudgee district lies near the northeast margin of the Lachlan Fold Belt and comprises sequences mainly deposited on the Capertee High (Fig. 1). In this paper, a detailed stratigraphy is presented for the southeast-trending belt of Late Ordovician to Late Silurian rocks which crops out along the Cudgegong River valley from Mudgee to Cudgegong. The belt is flanked to the northeast and southwest by Devonian sequences whereas in the south, the belt is intruded by the Carboniferous Aarons Pass Granite and unconformably overlain by Permian strata.

There are no known Cambrian rocks in the northeast Lachlan Fold Belt. However, by the Early Ordovician deep water flysch sequences were common with scattered mafic volcanic centres and associated shoalwater limestones developing in the Parkes, Wellington, and Molong areas (Cas, 1983). These conditions continued into the Late Ordovician where the dominant feature in the eastern Lachlan Fold Belt was the north-northwest-trending Molong High — a volcanic arc producing andesitic centres with flanking shoalwater limestones and volcaniclastics in an otherwise flysch-dominated environment (Powell, 1983b; Cas, 1983).

Deformation at the end of the Ordovician apparently continued into the early Middle Silurian (Crook *et al.*, 1973) and heralded the onset of a tensional regime in the

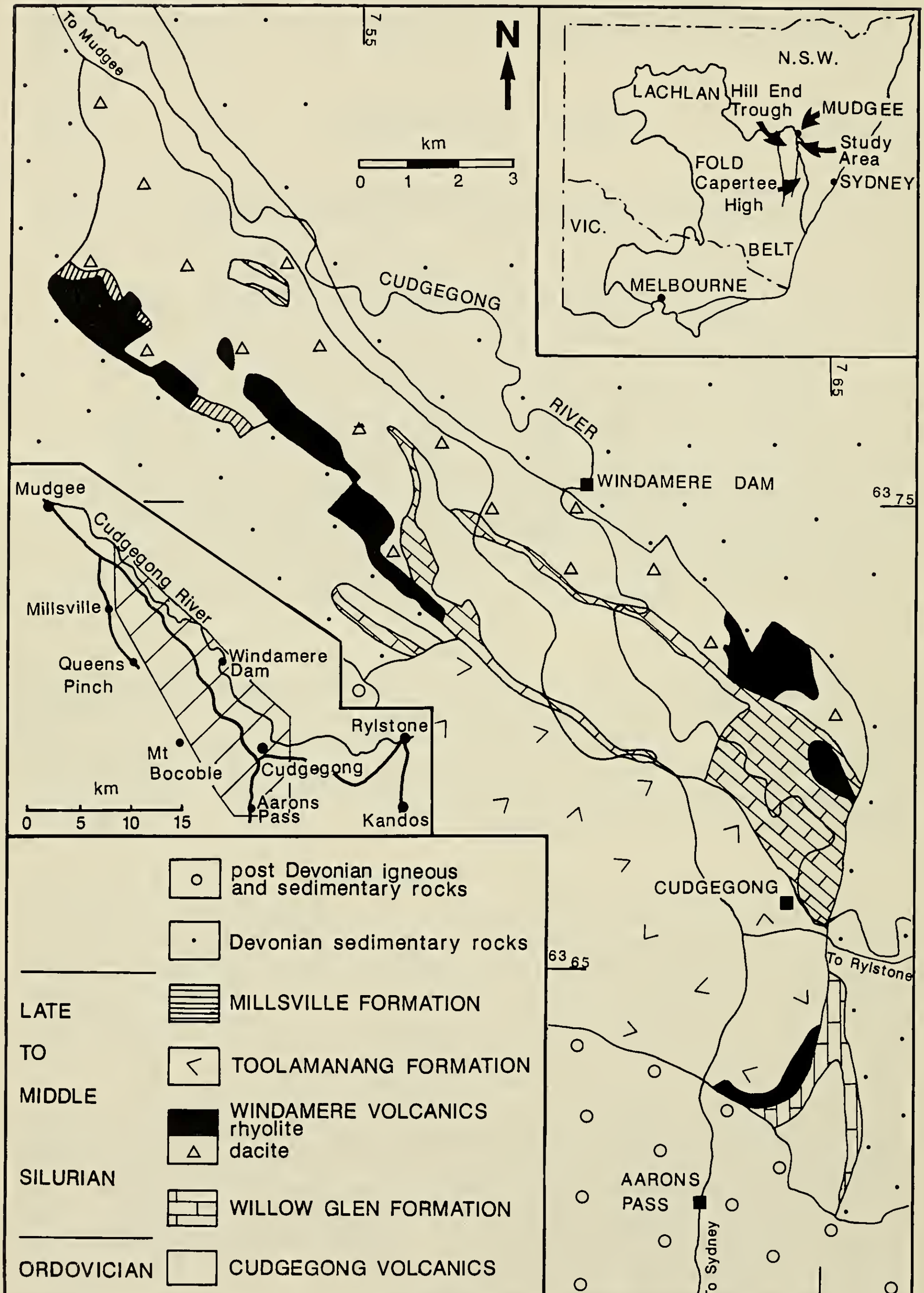

Fig. 1. Ordovician-Silurian geology of the Cudgegong-Mudgee district.

Late Silurian which produced regionally extensive silicic magmatism and extensional marine basins (Pickett, 1982b; Powell, 1983b). In the northeast, the deformation initiated rifting of the Molong High producing the opening of the Hill End Trough as a deep-water basin flanked to the east by a rifted fragment which produced the Late Ordovician basement for the developing Capertee High (Gilligan and Scheibner, 1978). Limestones, epiclastics, and extensive silicic volcanics represent Late Silurian shallow marine deposition on both the Molong and Capertee Highs whereas detritus for the infilling Hill End Trough was derived from the volcanism (Pickett, 1982b). On the east margin of the Lachlan Fold Belt, this configuration continued through the Early Devonian.

By the Middle Devonian, much of the Lachlan Fold Belt had been uplifted and intensely deformed, and proven Middle Devonian strata are limited to the Capertee High (Pickett, 1982b). However, there is a marked facies difference between the Early and Late Devonian sequences, accompanied by low angle discordant contacts along the northeast margin. The Late Devonian fluviatile and marine conditions (Powell, 1983a) continued into the Early Carboniferous and the orogenic history of the Lachlan Fold Belt concludes with terminal deformation in the late Early Carboniferous (Powell and Edgecombe, 1978; Cas, 1983).

Previous Geological Investigations

The first major treatment of the geology of the district was that of Game (1935) in which he mapped a wide tract of Silurian and Devonian strata from Mudgee to Aarons Pass and Kandos. He considered that a central belt of Upper Devonian rocks was faulted against Upper Silurian sequences. Mapping by the present author in the southwest Silurian belt has shown that: the sequence includes both Ordovician and Late Silurian rocks; conformable and unconformable contacts exist; the Ordovician-Silurian rocks are folded into a large scale anticline; and the strata may be locally overturned. Clearly this revised stratigraphy greatly affects part of Game's interpretation.

Wright (1966) produced a major contribution to the understanding of the Devonian stratigraphy and faunas and, in particular, to the subdivision of Game's Upper Devonian sequences on the basis of Early and Late Devonian faunas. In addition, he recognized that many of Game's limestones in the Queens Pinch area were, in fact, Early Devonian.

On the Dubbo 1:250 000 geological sheet, Offenberg *et al.* (1971) portrayed, in the Cudgegong-Mudgee district, the Devonian sequences of Wright (1966) flanking a central area in which they recognized the Ordovician Sofala Volcanics and the Siluro-Devonian Gulgamree Beds. However, mapping by Powis (1975), Michie (1975) and Pemberton (1977) raised doubts as to the validity of this nomenclature. Recent mapping by the author indicates that the proposed extent of the Sofala Volcanics of Offenberg *et al.* includes both Ordovician basaltic sequences and Silurian dacitic sequences. In addition, Wright (pers. comm.) considers their use of the Gulgamree Beds to far exceed his original description of the unit which, in any case, is probably a lateral equivalent of the Mullamuddy Formation in the Queens Pinch Belt. Most of the sedimentary rocks placed in the Gulgamree Beds by Offenberg *et al.* (1971) are now mapped as the Willow Glen Formation (Pemberton, 1980b).

Cudgegong Volcanics (Lavers 1960)

The Cudgegong Volcanics, the oldest rocks in the district (Fig. 2), were first mentioned by Lavers (1960) and subsequently by McManus *et al.* (1965). These rocks, to the southeast of Cudgegong, have subsequently been described by Pemberton (1980a).

Further mapping has revealed four separate outcrop areas of the Cudgegong Volcanics (Fig. 1; I, II, III and IV from Fig. 3).

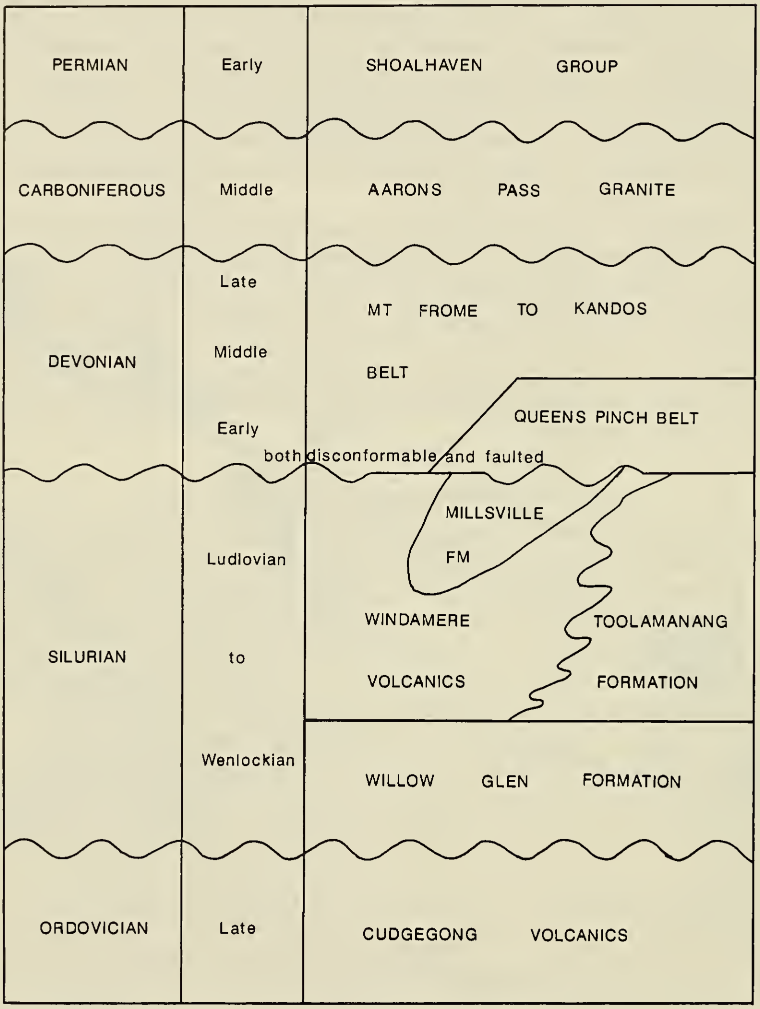

Fig. 2. Stratigraphy of the Cudgegong-Mudgee district.

Stratigraphic Relationships

In each of the four outcrop areas, the Cudgegong Volcanics are unconformably overlain (the contact is not exposed) by the Willow Glen Formation, or are faulted against younger rocks. The base of the Volcanics is not exposed.

The areas consist mainly of fine- to medium-grained andesitic arenite, basaltic rocks being generally rare. Exceptions include: the southeast area (IV) where abundant basaltic textures and compositions are modified by the contact metamorphism of the Aarons Pass Granite; common basaltic arenite throughout the southwest area (II); and the larger central area (III, Fig. 3) which provides the best exposures of the basaltic rocks and andesitic lava. In the northwest of the latter area, lava, with probable pillows, fine- to coarse-grained arenite and breccia together with andesite lava and possible syenite sills suggest proximity to a basaltic source (Cas and Wright, 1987). To the southeast, near Limestone Creek, there is a fining in fragment sizes within near continuous basaltic exposures and here the fine- to medium-grained basaltic arenite may indicate a more distal aspect from the possible northwest source. The basaltic exposure, near the southwest margin (GR 615695), consists of lava, with probable pillows, arenite and minor breccia.

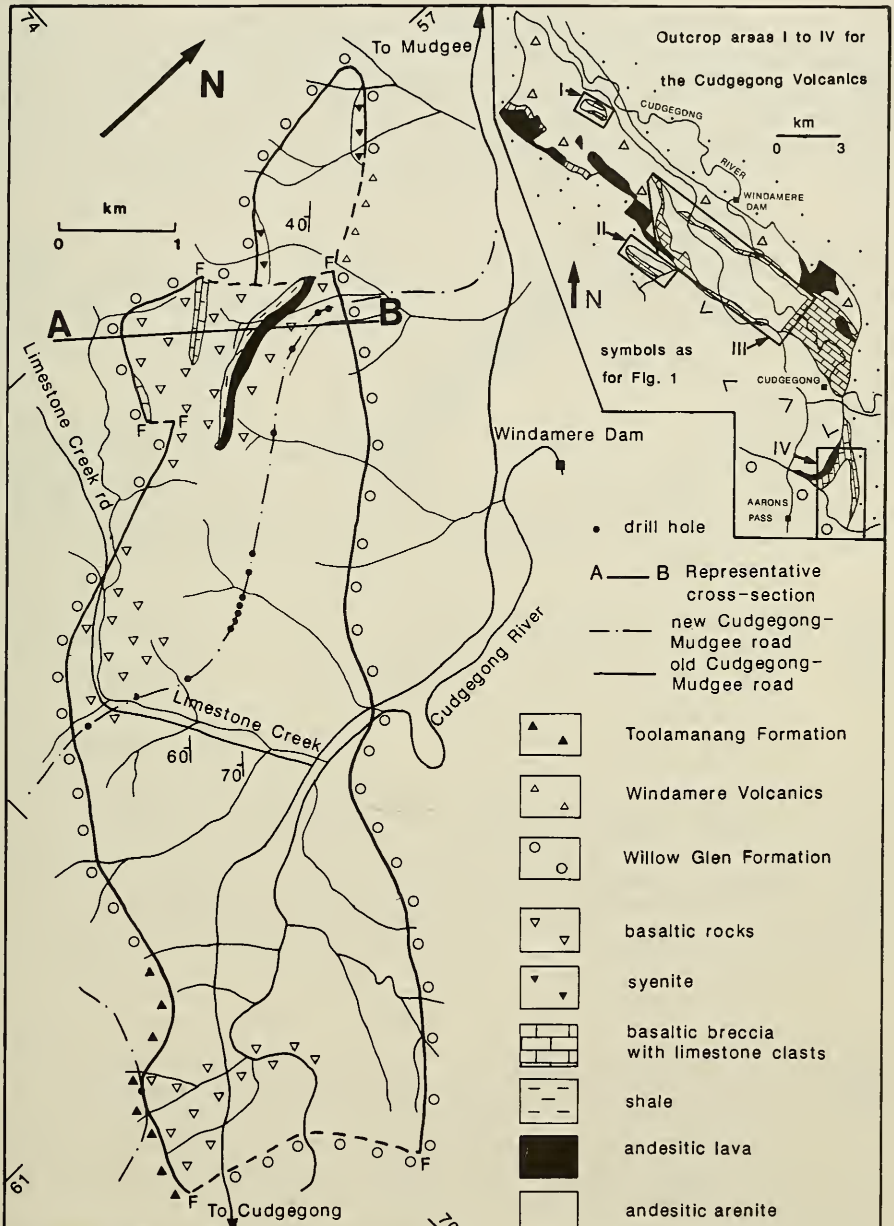

Fig. 3. Geology of the central area (III) of the Cudgegong Volcanics.

All areas display rapid lateral lithological variation and recognition of marker horizons is difficult. The exception is in the northwest of the central area (Fig. 3) where a number of distinctive horizons of the less common rock types are exposed. These include andesite lava, shale, breccia with abundant limestone clasts and syenite horizons.

TABLE 1

Petrography of the main rock types in the Cudgegong Volcanics

basalt lava SiO_2=48–54% (in basalt to basaltic andesite range)	Porphyritic with phenocrysts of subhedral to euhedral clinopyroxene (glomeroporphyritic, twinned, zoned, diopside to augite, 11 to 34%) to 7mm across; subhedral to euhedral plagioclase (albite, 0 to 18%) to 5mm long; and rare subhedral amphibole (pargasite, X=colourless, Y=light green, Z=green/brown) to 2mm across. Groundmass (50 to 59%) pilotaxitic to cryptocrystalline (usually recrystallised) of albite laths, clinopyroxene and rare amphibole subhedra, tremolite, sphene, chlorite, calcite, epidote and pyrite. Rare ovoid amygdales contain chlorite and calcite. Clinopyroxene chemistry and significance detailed in Pemberton and Offler (1985); relatively unaltered with chlorite and calcite along fractures in cores, and tremolite rims on more altered grains. Albite strongly altered to sericite, chlorite and calcite. Initial glassy groundmass devitrified and now dominated by chlorite and sphene. Calcite, chlorite, epidote, albite, prehnite, pumpellyite and quartz common in porphyroblastic aggregates.
basaltic arenite	Very fine- to very coarse-grained (0.01 to 2mm), moderately sorted in ash fractions to poorly sorted in coarser rocks, immature. Angular (larger grains are more rounded) phenoclasts of clinopyroxene (5 to 35%), plagioclase (albite, 15 to 34%) and rare pargasitic amphibole (0 to 8%); basaltic groundmass clasts (with or without phenocrysts, 19 to 43%). Matrix formed by recrystallisation and devitrification of finest fractions. Minor bedding and clast alignment; erosional contacts between size fractions suggest numerous pulses of activity rather than gravity settling; grain size gradational to basaltic breccia.
basaltic breccia	Very fine sand to cobble size (0.05mm to 10cm, rare boulders to 1m), very poorly sorted, immature. Angular (larger clasts are more rounded) basaltic lava cobbles and boulders; basaltic groundmass clasts (with or without phenocrysts, 26 to 61%); phenoclasts of clinopyroxene (15 to 28%), plagioclase (albite, 3 to 11%) and rare amphibole; limestone cobbles to 15cm and calcite grains to 3mm. Matrix recrystallised and devitrified material. Rare calcite cement. Larger limestone component (cobbles and grains) than basaltic arenite; clast alignment indicates minor current activity; slump deposit emphasised by sorting and clast size decrease away from larger clasts.
andesite lava SiO_2=53–57%	Porphyritic with phenocrysts of subhedral to euhedral plagioclase (albite, glomeroporphyritic, 25 to 35%) to 5mm long, and rare subhedral clinopyroxene (0 to 9%). Groundmass (50 to 58%) pilotaxitic, of albite laths with interstitial chlorite and sphene. Albite partially altered to sericite, chlorite and rare calcite. Clinopyroxene grossly altered to calcite and sphene. Original groundmass partly glassy; devitrified and now mainly chlorite and sphene. Porphyroblastic aggregates of calcite, epidote, chlorite and prehnite.
andesitic arenite	Very fine to coarse sand size (0.01 to 3mm), moderately sorted ash fraction to very poorly sorted in coarser rocks, immature. Angular (larger clasts are more rounded) phenoclasts of plagioclase (albite, 34 to 43%) and rare clinopyroxene; andesitic groundmass (with or without phenocrysts, 36 to 55%). Matrix formed by recrystallisation and devitrification of finest fractions; rich in chlorite and sphene. Minor bedding, clast alignment and size grading indicate some current activity.

Petrography

The Cudgegong Volcanics consist of lavas of basaltic, basaltic andesite and andesitic composition together with associated very fine- to coarse-grained arenite and breccia (Table 1). The rocks show the imprint of prehnite-pumpellyite to greenschist facies metamorphism (Offler and Pemberton, 1983).

Fauna, Age and Correlation

The only recognized fossils in the Cudgegong Volcanics are found in a thin marl, up to 20cm thick, underlying the basaltic breccia with limestone clasts marker horizon in the central area (Figs 3 and 4; GR 568733). Pickett (1982a) identified the coral *Plasmoporella* sp. and the alga *Vermiporella* sp. from autochthonous limestone beds in the marl. Pickett (1978) reported the same coral and alga, together with a Gisbornian conodont fauna, from limestone clasts in a breccia towards the top of the Sofala Volcanics.

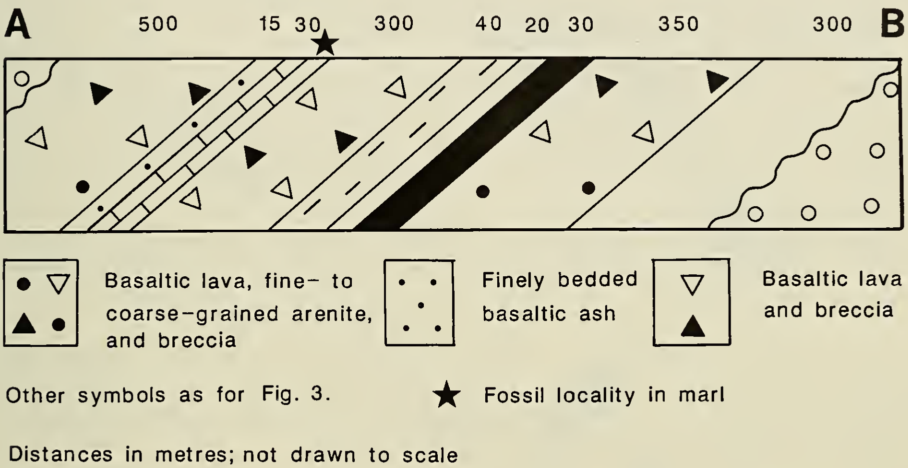

Fig. 4. Representative cross-section through the Cudgegong Volcanics.

The Cudgegong Volcanics are here correlated with the upper parts of the Sofala Volcanics on the basis of similarities in lithologies (Packham, 1968; Barron, 1976; Gilfillan, 1976), clinopyroxene chemistry (Pemberton and Offler, 1985) and fauna. The fauna occurs towards the south margin of the Cudgegong Volcanics where the strata are southwest dipping and apparently upright, and as this suggests the fauna occurs towards the top of the unit, a Gisbornian age is indicated for this part of the Cudgegong Volcanics.

Structure

The Cudgegong Volcanics in the central, northwest and southeast areas (III, I and IV respectively in Fig. 3) form the core of a northwest-trending anticline, with an overturned northeast limb. The southwest area (II) is considered part of a southwest-dipping Ordovician-Silurian block faulted into position against Devonian rocks.

Folding within the Volcanics cannot be recognized. Marker horizons, where present, are traceable only over short distances yet they strike parallel to the contact with the Willow Glen Formation and do not indicate any sequence repetition. In the central area (III), the sequence is apparently simply southwest dipping (data from finely laminated ash, flat bedded arenite and crudely aligned clasts in breccia) and younging, from the reworked top of an andesitic lava, indicates strata, near the south margin at least, are upright. Possible internal folding hinders attempts to produce a representative section for the Volcanics and as a compromise, a representative cross-section has been compiled for the northwest of the central area (Fig. 4).

Environment of Deposition

The majority of rocks in the Cudgegong Volcanics are immature, grain-supported arenite containing poorly sorted, randomly-oriented angular clasts of their respective lavas forming thick apparently structureless outcrops. The arenites satisfy many of Cas and Wright's (1987) criteria for formation by volcaniclastic debris flow.

The majority of arenites were derived from an andesitic parent; however, the outcrops display no features indicating possible source areas. Exposures of basaltic rocks are limited, yet in the northwest of the central area (III), a possible near-vent location is suggested by outcrops of basaltic breccia with limestone clasts, andesitic and basaltic lava and possible syenite sills which fulfil some of the required near-vent criteria (Williams and McBirney, 1979; Cas and Wright, 1987).

Preservation of limestone clasts in breccia together with the underlying marl in the northwest of the central area (III), calc-silicate and chert horizons in the southeast area (IV), and the identification of probable pillow lava (GR 619696 and GR 580747) indicate a marine environment for both the volcanic and quiescent periods. The autochthonous fauna in the marl indicate that in some areas, at least, shallow marine conditions prevailed.

The data suggest the Cudgegong Volcanics formed by slumping of unstable andesitic and basaltic debris from volcanic island slopes in a subaqueous environment.

WILLOW GLEN FORMATION (Pemberton 1980a)

The Willow Glen Formation, named after the former Willow Glen property 3km southeast of Cudgegong, was initially described and named by Pemberton (1980a). The extensive exposure of the unit was noted by Pemberton (1980b) and in this paper the previous description of the unit is reviewed and expanded.

Stratigraphic Relationships

The formation crops out in a number of separate areas (Fig. 1; areas (a) to (f) in Fig. 5). In each area, the unit is conformably overlain by the Windamere Volcanics (contact clearly exposed in the new Cudgegong-Mudgee road at GR 575748); the exception is the southeast area (f) where it is overlain conformably by the Toolamanang Formation.

The formation consists of conglomerate (dominated by silicic volcanic clasts) grading to pebbly litharenite and litharenite, shale, fossiliferous limestone, and rare rhyolite horizons (Table 2).

In the southeast area (f), Pemberton (1980a) established a sequence of basal litharenite, lower limestone bed (biomicrite with silty interbeds), massive dacitic ash grading to well-bedded shale, and upper limestone bed (biomicrite with abundant silicic volcanic clasts and common pentamerid brachiopods).

To the northwest, the formation differs markedly with the introduction of abundant lensoidal conglomerate horizons and thinly bedded shale and arenite with common limestone lenses. The most complete and representative exposure of these rocks occurs in the eastern portion of the central area (e from Fig. 5). Unfortunately these exposures lie close to the Cudgegong River and now the majority of these, together with several important fossil localities, are covered by the waters of Windamere Dam. Rocks typically exhibit rapid lateral facies change which produces considerable variation in

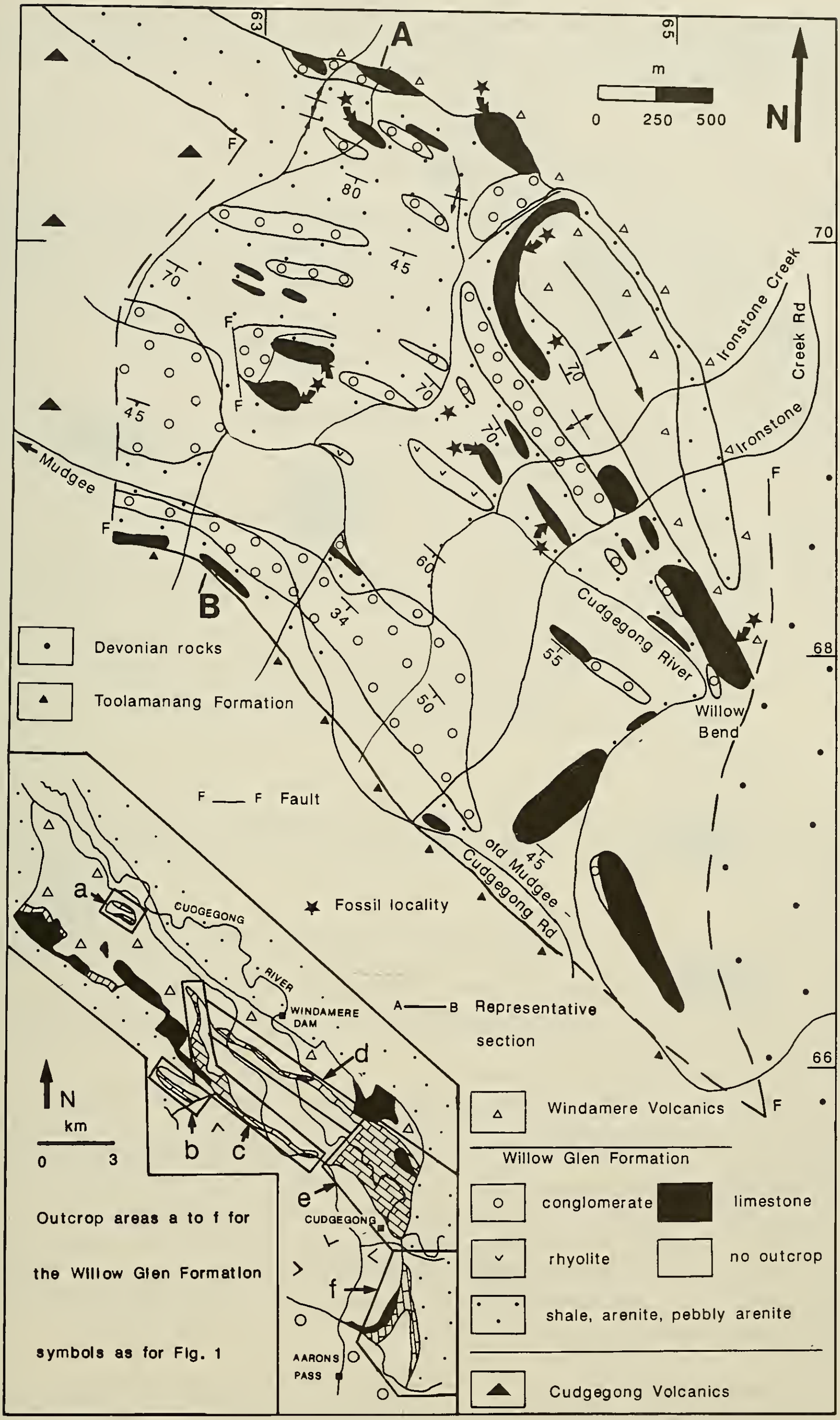

Fig. 5. Geology of the eastern portion of the central area (e) of the Willow Glen Formation.

both thickness and extent of the outcrops. Consequently the prominent conglomerate horizons, within the recessive shale, arenite and limestone, cannot usually be traced as marker horizons for distances greater than several hundred metres.

TABLE 2

Petrography of the main rock types in the Willow Glen Formation

conglomerate	Grey/white to red, very fine sand to cobble size (4cm), very poorly sorted, immature. Subrounded to rounded white and black silicic volcanic clasts (80%), fragmental plagioclase and quartz grains to 3mm, and rare shale, arenite and limestone clasts. Matrix of fragmental quartz and plagioclase; strongly recrystallised. Very fine siliceous cement, commonly with iron oxide or chlorite. Gradational to pebbly arenite. Plagioclase grains altered to sericite and calcite; matrix texture obscured by recrystallisation and abundant secondary calcite veining.
litharenite	Grey/brown to red, very fine– to coarse–grained (2mm), moderately to poorly sorted, immature. Angular to subrounded (larger grains are more rounded) silicic volcanic, plagioclase, quartz and calcite grains with rare shale clasts. Matrix strongly recrystallised; cement siliceous with common secondary iron oxide and chlorite. Common secondary calcite veins and irregular–shaped aggregates mask much of texture.
shale	Grey/brown, very fine–grained siliceous material with rare angular quartz and plagioclase grains to 0.1mm. Abundant aligned secondary white mica.
limestone	Unsorted biomicrite and biosparite, and intrasparite; all with common detrital silicic volcanic clasts, and quartz and plagioclase grains. Silicic volcanic pebbles (3cm) abundant in upper limestone bed of southeast outcrop area. Jones et al. (1987) report oolitic limestone (intrasparite) from GR 652679.

Stratigraphic sections from all outcrop areas are included in Fig. 6. The thickness of section 2 may be exaggerated as the sequence through area (e) is probably repeated by folding. Comparison of these sections has emphasized a number of similarities and differences.

First, the majority of the Willow Glen Formation consists of lensoidal conglomerate, arenite and pebbly arenite horizons within a fossiliferous sequence of thinly bedded shale and arenite with limestone lenses. The two obviously different areas are: the southeast area (f; section 1 of Fig. 6) where conglomerate is absent and shale with limestone lenses are sparse; and at the northwest of area (d) (section 6 of Fig. 6) which is dominated by thick lensoidal conglomerate.

Second, the distinctive pebbly limestone (abundant silicic volcanic clasts and common pentamerid brachiopods) of the upper limestone bed, southeast area (f) also occurs in the limestone horizon in the southwest area (b); the southeast limestone bed of area (c) (GR 612698); and numerous limestone lenses in the eastern portion of the central area (e). Similar limestones are not recorded in the northwest of the district.

Third, the thickness of the sections and the outcrop width of the areas varies dramatically and this suggests that the top of the formation was not a flat topographic surface, rather that the essentially conformable Windamere Volcanics filled erosional or nondepositional depressions on this surface.

Fauna, Age and Correlation

Numerous fossil localities have been recorded from shales (brachiopods and trilobites) and limestones (brachiopods and corals) in the Willow Glen Formation (faunal

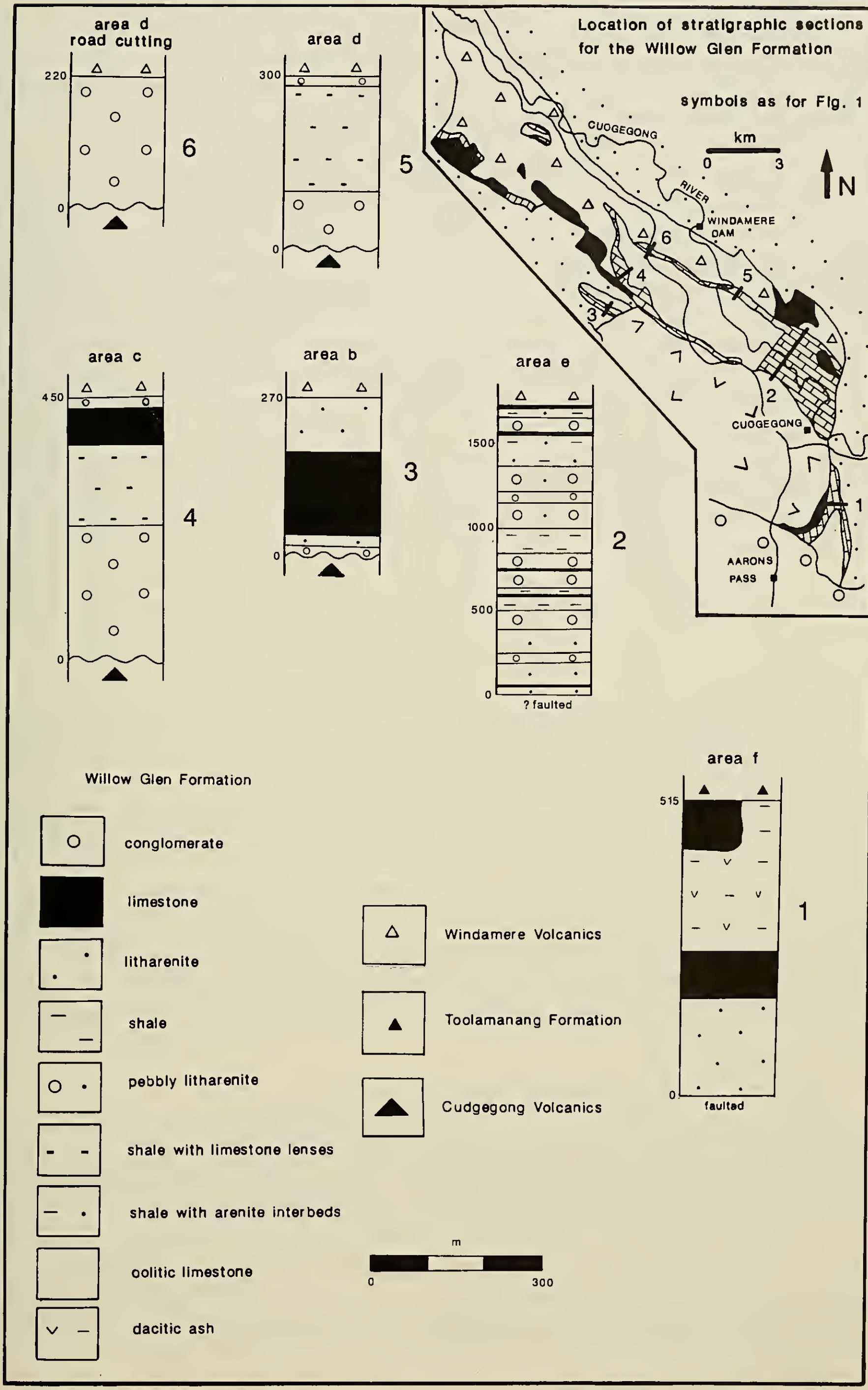

Fig. 6. Representative stratigraphic sections for the outcrop areas of the Willow Glen Formation. No section from the northwest area.

lists in Appendix). Pickett (1982a) proposed a Wenlockian to Ludlovian age based on the identification of the brachiopod *Kirkidium* and the corals *Phaulactis*, *Halysites orthopteroides*, *Desmidopora multitabulata*, and *Pycnostylus scalariformis* from the limestone localities. Recovery of conodonts from limestone samples was low with the best-preserved specimens being referable to *Ozarkodina ranuliformis*, a species considered to occur over a broad Silurian age in Australia (Pickett, 1982a).

Strusz (pers. comm., 1984) recognized that the Willow Glen Formation shale fauna was similar to part of the fauna from Coppin's Crossing, near Canberra (Strusz, 1982). He identified the brachiopods *Salopina ?mediocostata*, *Aegiria* cf. *norvegica*, *Morinorhynchus oepiki* and *Coelospira cavata*, together with *Maoristrophia* (Strusz, 1983) and the trilobite *Encrinurus mitchelli* (Strusz, 1980). He suggested a Late Wenlockian to Early Ludlovian age for the fauna.

Silurian sedimentary sequences unconformably overlie Sofala Volcanics equivalents at at least four known localities: Sofala and east of Wattle Flat (Packham, 1968); Palmers Oakey (Powell, 1984, based on Bischoff and Fergusson, 1982) and now at Cudgegong. In the Sofala-Wattle Flat area, Packham (1968) identified a coral-trilobite-brachiopod fauna, with sparse graptolites, from the Tanwarra Shale. Based on tentative identification of the graptolites, he suggested the Tanwarra Shale may be as old as Late Llandovery. However, in the Tanwarra Shale equivalents at Palmers Oakey, Bischoff and Fergusson (1982) recognized a very Late Wenlockian age for an extensive conodont fauna. The Late Wenlockian to Early Ludlovian age proposed for the Willow Glen Formation, after Pickett's and Strusz's faunal identifications, is consistent with the age of the strata at Palmers Oakey and perhaps the age of the Tanwarra Shale at Sofala.

Structure

The southeast, northwest and central areas (f; a; and c, d and e respectively from Fig. 5) lie on the limbs of an anticline whereas the southwest area (b) is part of an Ordovician-Silurian block faulted against Early Devonian strata.

In both the southeast and northwest, bedding data are limited and mapping of formation boundaries and age relationships indicate the anticlinal structure. Bedding data from the upright southwest-dipping area (c) have a mean limb dip of 35° with a modal strike of 315° whereas data from the southwest-dipping overturned (facing from cross-bedded pebbly arenite) areas (d) and (e) have a mean dip of 75° with a modal strike varying from 310° to 320°. Combined limb data indicate a near-horizontal fold plunge with both southeast and northwest plunge components. Within-limb parasitic folding is common, with similar fold styles and plunge to the large scale structure.

Environment of Deposition

Conglomerate, arenite and pebbly arenite horizons

These horizons have many features indicative of a fluvial channel-fill origin. These include the very poorly-sorted yet well-rounded nature of the clasts; common interbedding of lithologies producing flat lamination, with clast alignment in the coarser beds; cross-bedding with pebbles aligned parallel to, and with fining upwards sequences in, the cross beds as well as low angle beds asymptotic to the cross-bed base; and their lensoidal shape. The lenses vary greatly in thickness (a few metres up to 200m) and lateral extent (10m up to several km) providing evidence for an extensive channel system preserving single channel-fill events (thickness in the order of 5m) as well as multiple channel-fill build-up.

Shale and arenite with limestone lenses

Strusz (pers. comm., 1984) noted the faunal and lithological similarity of these rocks to the strata near Coppin's Crossing, Canberra (Strusz, 1982). He considered the latter to represent Boucot's (1975) benthic assemblage 3 — the subtidal zone with both quiet and rough water reef communities below 6m water depth. The thinly bedded fossiliferous shale, arenite and *in situ* limestone of the Willow Glen Formation represent a dominantly quiet water, low energy environment. The thicker lensoidal limestones may indicate local mounds with rough water conditions, as indicated by the pentamerid-coral fauna (Boucot, 1975), and provide the higher velocity currents necessary to transport and deposit the silicic volcanic pebbles typical of some of these limestones.

The detailed study of the strata at Willow Bend (GR 652681 from Fig. 5; Jones *et al.*, 1987) demonstrates a thin clastic regressive unit within open-marine limestone. The basal shale (low energy subtidal environment below storm wave base) is sharply overlain by a very shallow marine oolitic limestone which was later subjected to evaporation on supratidal flats. The sequence was then partly eroded by fluvial scours prior to transgression with initially another localized oolitic limestone and then by more open-marine limestone.

In summary, the majority of the formation represents deposition on subtidal to supratidal flats affected by transgressive/regressive cycles. The overall pattern is one of fluctuating sea level and energy regimes with localized rough water limestone mounds surrounded by quiet water deposition. The inferred flats were incised by fluvial channels accompanying periods of sea-level regression.

Variations

The northwest of area (d) and the southeast area (f) are lithologically different from the majority of the formation. In the former area, thick conglomeratic horizons represent substantial fluvial channel-fill accumulations possibly providing the source direction for the channel system incising the tidal flats to the southeast and southwest. By comparison, in the southeast area, the absence of conglomeratic horizons, and the thick ash/shale and arenite beds with poorly fossiliferous limestone suggest open-marine conditions to the southeast of the tidal flats.

Depositional setting

Comparison of the Willow Glen Formation from the northwest to the southeast of the district indicates a typical 20-25km wide coastal zone, similar to present-day examples along the north and northeast Australian coast, with progression from the fluvial channel zone through a tidal flat to more open-marine conditions.

WINDAMERE VOLCANICS (Pemberton 1980b)

These rocks were included by Offenberg *et al.* (1971) in the Sofala Volcanics. However, recognition of their Late Silurian age and dacitic nature led Pemberton (1980b) to propose the Windamere Volcanics, named after the former property upstream from the Windamere Dam wall.

Stratigraphic Relationships

The formation crops out to the northwest of Cudgegong initially as a 1km-wide belt which widens northwest of Windamere Dam reaching a maximum width of 4km in the Millsville area (Fig. 1). These exposures lie on the limbs of the major northwest-trending anticline and have been described (data summarized in Table 3) as the northern limb (Fig. 7) and southern limb (Fig. 8).

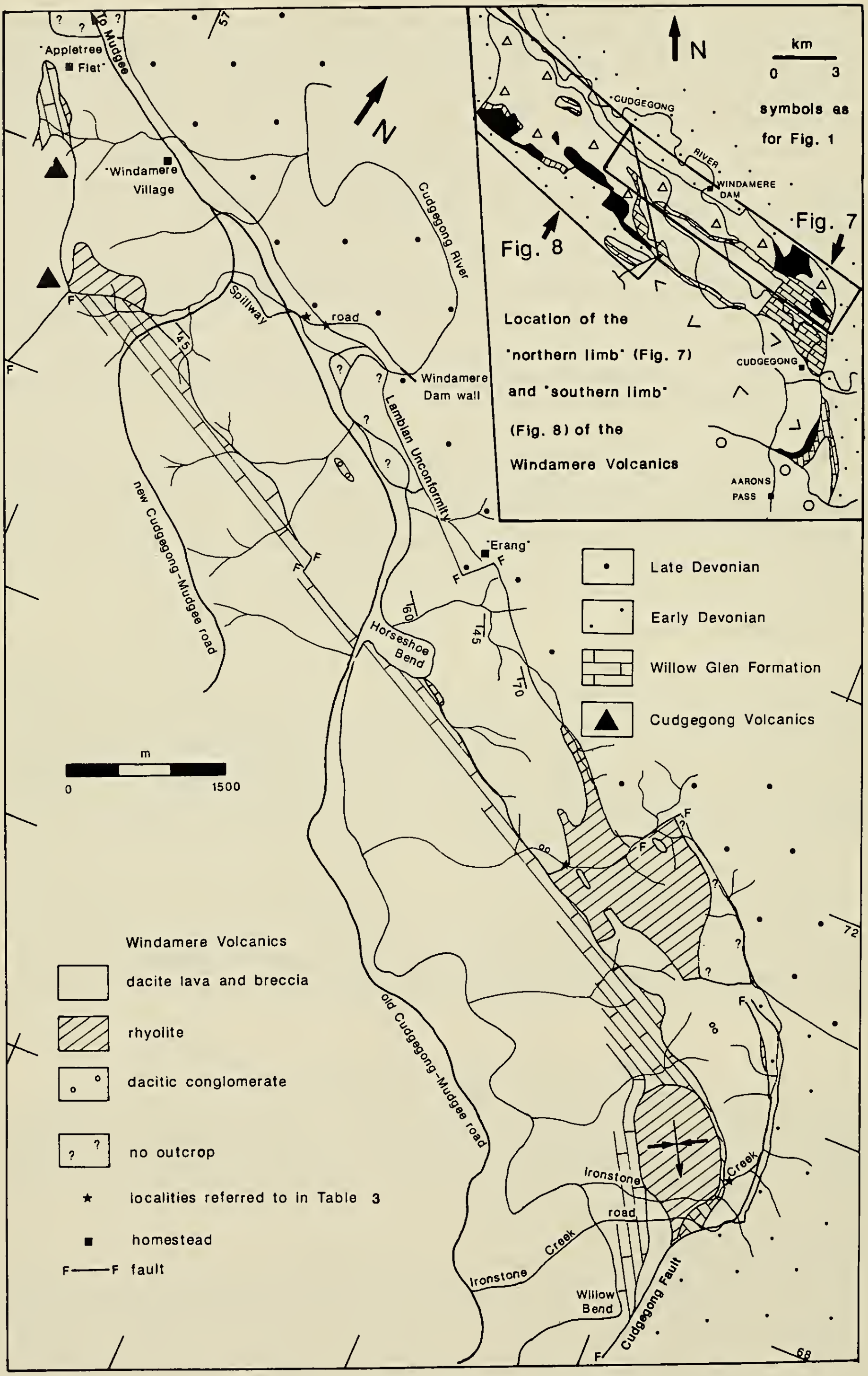

Fig. 7. Lithological variation for the northern limb of the Windamere Volcanics.

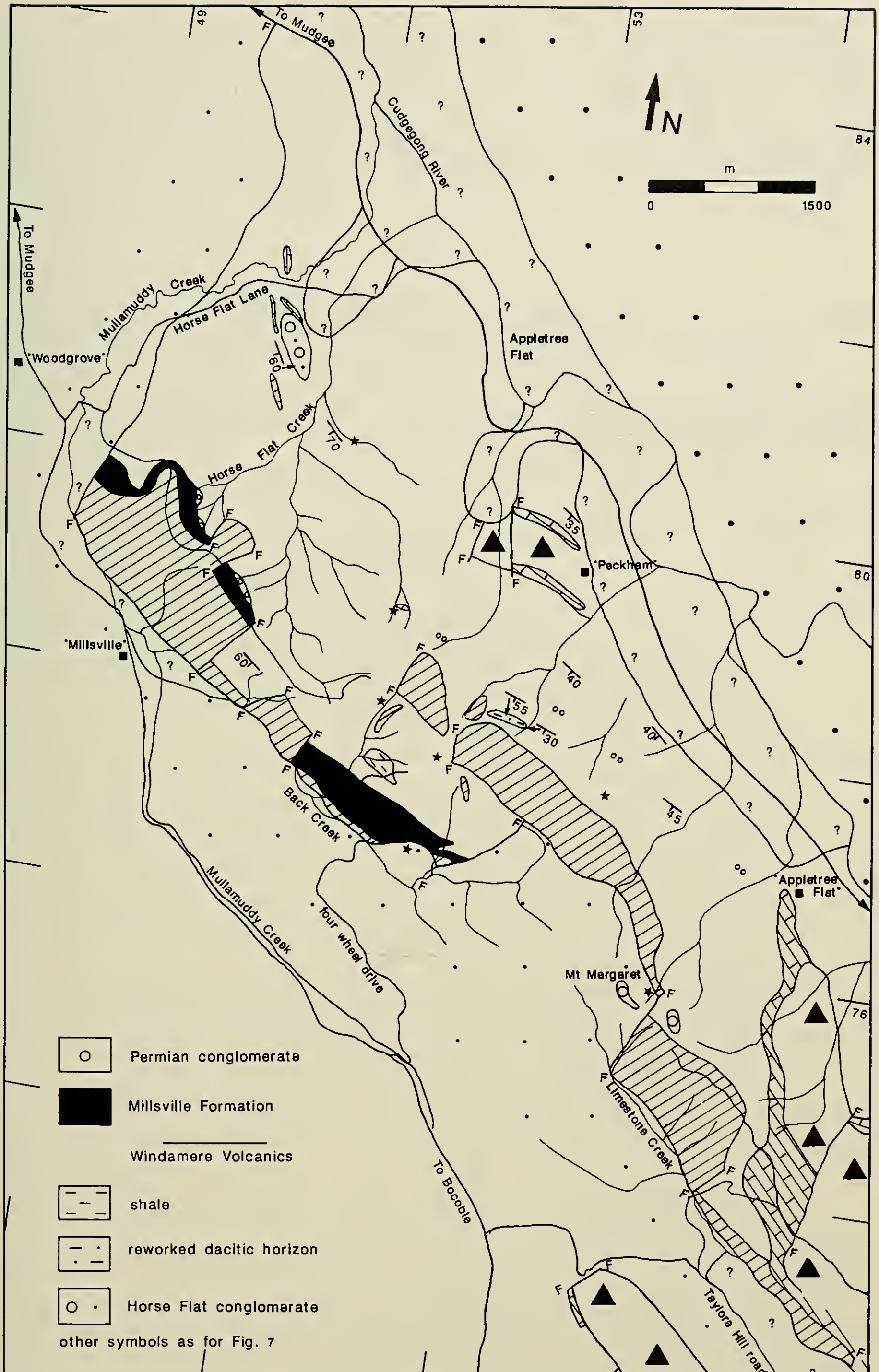

Fig. 8. Lithological variation for the southern limb of the Windamere Volcanics.

Petrography

The Windamere Volcanics are characterized by thick and extensive exposures of undifferentiated dacite lava and breccia, with common rhyolite horizons at all stratigraphic levels (Table 4). Less common rock types include dacitic arenite (with sparse pebbles) to rare ash-size rocks; dacitic conglomerate; dacitic breccia with limestone clasts; flow layered dacite lava; and shale, with rare limestone clasts. Positions in the sequence and best exposures are included in Table 3.

TABLE 3

Extent of and sequence within, the Windamere Volcanics Extent

Northern limb	Overturned limb bounded by unconformity with Late Devonian rocks along Cudgegong River valley and to southeast by Cudgegong Fault. Unit top not exposed yet conformably underlain by Willow Glen Formation over outcrop length.
Southern limb	Provides more complete sequence with both conformable underlying (Willow Glen Formation) and overlying (Millsville Formation) contacts, the latter only in certain northwest localities. The Millsville Formation and rhyolite of Windamere Volcanics are both disconformable and faulted with Early Devonian strata of Queens Pinch Belt.

Sequence and best exposures

Basal sequence	Dominated by dacite lava and breccia. Variations include: numerous conformable rhyolite horizons, to several m thick, both at base and slightly higher in sequence; in Ironstone Creek (GR 657692), 5m of dacitic arenite with limestone and rhyolite clasts, and black shale, with limestone lenses, occur above an initial 20m of dacite lava (contact not exposed); and on Horse Flat (GR 503810) Willow Glen equivalents are sharply overlain by 100m of coarse conglomerate (dacite and rhyolite clasts), pebbly arenite and arenite.
Middle sequence	Dacite lava and breccia dominant (extensively exposed in new road cuttings and dam spillway), with greater diversity of less common rock types. Include: dacite lava with polygonal cooling joints; dacite lava with rounded mafic xenoliths to several cm across; flow layered dacite lava; discontinuous dacitic conglomerate beds; rare dacitic breccia with limestone clasts; coarse dacitic breccia with flow layered clasts to 1m across (GR 522774); common thin conformable rhyolite horizons; and 25m thick reworked dacite horizon (GR 528781) of thinnly bedded arenite, shale with sandy interbeds (ripple marks), coarse breccia, conglomerate with arenite beds (cross-beds and scour and fill structures). Facing from sedimentary structures indicate horizon upright.
Upper sequence	Proportion of detrital dacitic rocks increases within dominant dacite lava and breccia. Detrital lithologies include: breccia with limestone clasts; arenite and pebbly arenite; 100m thick shale bed (GR 518774). with rare thin limestone and conglomerate lenses; and 10m thick dacite boulder horizon (GR 518771) only a few m below conformably overlying Millsville Formation.
Rhyolite	Flow layered lava, with rare breccia and conglomerate, occurs at all stratigraphic levels. Thickness varies from few m to 100m, with thicker horizons as prominent ridges. On the southern limb, one such 100m thick apparently conformable body of flow layered lava forms prominent steeply southwest-dipping scarp for 5.5km length. Best conformable contacts with dacite at GR 507777 and GR 630716.

Primary dacite lava is distinguished from the fragmental rocks by the lack of fragmental phenocrysts (rounded, embayed quartz, subhedral to euhedral plagioclase and amphibole); the glomeroporphyritic nature of phenocryst aggregates; the presence of rare amygdales; and the clear distinction between phenocrysts and groundmass (15 to 35% phenocrysts with the maximum density 49%). However, recognition of primary textures is hindered by the effects of prehnite-pumpellyite to greenschist facies metamorphism. Moreover, recrystallization of the groundmass produces granoblastic quartz masses. Further, breakdown of the groundmass varies from the minor development of fine-grained interstitial chlorite to the major development of distinct chlorite-rich and quartz-rich portions, the latter producing a brecciated appearance. Another feature hindering the recognition of primary textures, especially in rocks towards the top of the formation, is the secondary silicification of highly fractured dacitic rocks and the development of siliceous spherulitic concretions in numerous rhyolite horizons.

TABLE 4

Petrography of the main rock types in the Windamere Volcanics

dacite lava SiO_2=65–69%	Porphyritic with phenocrysts of subhedral plagioclase (albite, glomeroporphyritic, 11 to 32%) to 5mm long; embayed quartz (fractured, 0 to 6%, fine-grained recrystallised margins) to 3mm across; and rare subhedral to euhedral amphibole (hornblende, 0 to 9%, X=pale brown, Y=light brown, Z=brown/green) to 1mm long. Fine-grained and recrystallised groundmass (51 to 87%) dominated by anhedral quartz and plagioclase. Rare ovoid amygdales contain chlorite. Albitised plagioclase phenocrysts and groundmass grains partially altered to chlorite, sericite, epidote, pumpellyite, prehnite and calcite. Chlorite very common in groundmass (to 16%) as interstitial material in less altered rocks, and as irregular-shaped masses, to several mm across, and as pseudomorphs after plagioclase and amphibole in more altered rocks. In the most altered rocks, groundmass segregates into quartz-rich and chlorite-rich portions.
dacite breccia	Very fine-grained to cobble size (0.01mm to 10cm; rare boulders to 1m), very poorly sorted, immature. Angular (rounded larger clasts) dacite lava cobbles and boulders, dacite groundmass clasts, plagioclase and quartz phenoclasts. Matrix of finest sized dacite fragments (dominated by recrystallised quartz and plagioclase). Rare primary calcite cement. Alteration of phenocrysts and groundmass similar to that described for dacite lava. Development of metamorphic textures, in particular breakdown of groundmass, may hinder recognition of primary fragmental nature.
dacite arenite	Very fine-grained to very coarse-grained sand (0.01 to 3mm), poorly sorted, immature. Angular dacite groundmass clasts, quartz and plagioclase phenoclasts, and rare dacite lava clasts. Matrix formed by recrystallisation and devitrification of finest dacitic fraction. Alteration as described for dacite lava and breccia. Sharp erosional contacts between varying grain sizes.
rhyolite lava	Sparsely porphyritic with phenocrysts of embayed quartz (finely recrystallised margins) to 3mm across, and rare subhedral feldspar (strongly altered, untwinned) to 5mm long. Coarsely recrystallised groundmass of polygonal quartz and irregularly- shaped altered feldspar. Common flow layering as compositional banding of quartz-rich and -poor horizons to 5mm thick. Feldspar phenocrysts very strongly to completely altered to sericite and chlorite; groundmass grains less severely sericitised. Spherical siliceous concretions, to 4cm across, are very abundant towards the top of the unit.

Age and Correlation

No fauna has, as yet, been found in the Windamere Volcanics. However, the unit is considered Late Silurian as it is conformably underlain and overlain by Wenlockian to Ludlovian strata — the Willow Glen Formation and the Millsville Formation. Rhyolite overlying the latter is disconformably overlain by Early Devonian strata.

In the Sofala district, rhyolite lava, arenite and breccia (the Wenlockian Bells Creek Volcanics of Packham, 1968) conformably overlies the Tanwarra Shale and is overlain conformably by the deep water Chesleigh Formation deposited on the eastern margin of the Hill End Trough.

Structure

The outcrop areas of the Windamere Volcanics lie on the limbs of the major anticline. On the southern limb, facing (from the reworked dacitic horizon and the conformably overlying Millsville Formation) indicates the southwest-dipping sequence is upright. A composite representative section (Fig. 9) has been compiled from the basal contact with the Willow Glen Formation on the Peckham property (Fig. 8), incorporating a number of northeast-southwest traverses, to the uppermost rocks, including the Millsville Formation, below the Early Devonian disconformity along Back Creek (GR 521766). The southwest-dipping strata of the northern limb are considered overturned, based on the relationship with older units as well as cleavage vs bedding orientation.

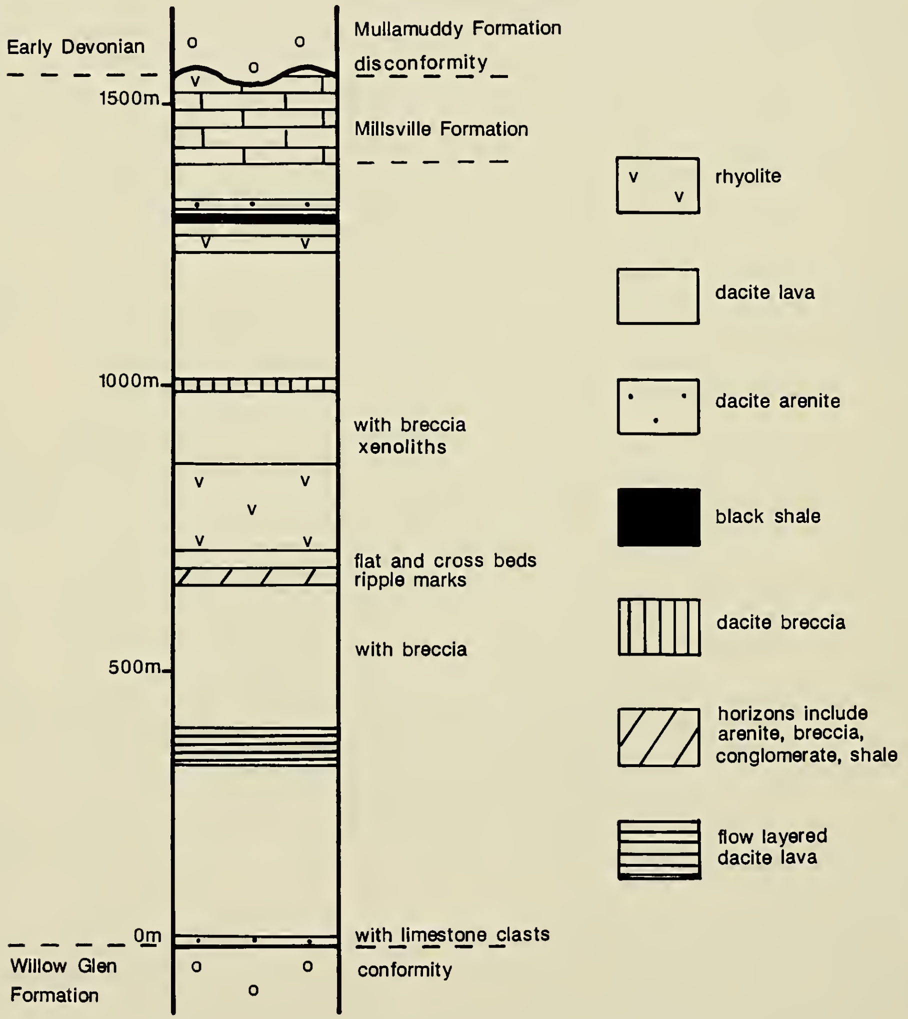

Fig. 9. Composite representative section through the Windamere Volcanics.

Common northeast-trending faults clearly offset rhyolite horizons on the southern limb (Fig. 8), as well as the Millsville Formation; the Cudgegong Volcanics-Willow Glen

Formation sequence; contacts with the Devonian strata and Devonian sequences in the Queens Pinch Belt. A similar pattern of faults affects strata on the northern limb (Fig. 7). The displacement along the faults varies from small scale (several metres) up to hundreds of metres. The faulting is approximately normal to the regional fold axis and probably represents tear or compartmental faults (Davis, 1984) which formed during the regional folding and acted as transverse strike-slip faults accommodating the deformation of a thick rock mass.

Environment of Deposition

The eruptive environment, at least during periods of volcanic quiescence, is considered to have been shallow marine to probably emergent. Evidence includes: shale, with apparently *in situ* limestone lenses, at the base and top of the unit; shale, arenite and breccia, all with limestone clasts; and traction current structures (in the reworked horizon [GR 528781]) indicating fluctuating energy conditions in a shallow marine environment. In addition, the lensoidal conglomeratic body on Horse Flat (GR 510815, Fig. 8) together with other common conglomeratic lenses (Table 3) suggest a fluvial channel origin. Further, the underlying Willow Glen Formation was deposited in a shallow marine to supratidal environment with regression to subaerial conditions and the overlying Millsville Formation includes shallow marine and beach deposits.

The eruption of silicic lava into a shallow marine to subaerial environment should produce dominantly pyroclastic detritus with short thick lava bodies of limited aerial extent (Cas and Wright, 1987). However, the Windamere Volcanics are dominated by dacite lava, with less common breccia and rhyolite horizons.

An explanation for the high volume of dacite lava could be emplacement as a lava dome. The growth of silicic domed masses around vents, and shallow intrusions (cryptodomes), is preceded by highly explosive activity followed by long periods of non-explosive dome growth capable of producing thick lava masses. Recent subaerial examples include activity at Mt St Helens (Swanson *et al.*, 1987), the islands of Lipari and Vulcano (Sheridan *et al.*, 1987) and the South Sister volcano (Scott, 1987). The initial explosions decrease the volatiles available for later magmatic pulses thus providing the degassing mechanism for emplacement of thick non-explosive lava bodies (Fink and Manley, 1987). However, Newhall and Melson (1983) record numerous examples of post-dome explosions which activated partial dome collapse and led to autobrecciation of parts of the lava body.

If the Windamere Volcanics were emplaced as a thick domal body, the initial degassing mechanism may have produced the fragmental material of the Toolamanang Volcanics, a lateral mass-flow equivalent of the Windamere Volcanics. The common breccia may have formed from later explosive events causing autobrecciation by small scale dome collapse. In this model the abundant conformable rhyolite horizons could be either extrusive (with the thicker bodies towards the top of the volcanics representing terminal activity) or emplaced as contemporaneous sills.

TOOLAMANANG FORMATION (Pemberton 1980a)

The unit was named after the historic Toolamanang property, south and southwest of Cudgegong. To the southeast of Cudgegong, Pemberton (1980a) recorded rhyodacite lava, breccia and arenite (the Toolamanang Volcanics); these rocks had been assigned by Offenberg *et al.* (1971) to the Sofala Volcanics. Subsequent mapping to the southwest of Cudgegong (Pemberton, 1980b) revealed much greater exposure of the unit with a lack of primary volcanic features; thus the original description of the Toolamanang Volcanics has been considerably modified.

Stratigraphic Relationships

To the southeast of Cudgegong, the Toolamanang Formation overlies the Willow Glen Formation with apparent conformity (Pemberton, 1980a). However, to the north-west along Limestone Creek valley, the unit is faulted against Ordovician and Silurian rocks where the contact is marked by a prominent ferruginous zone tens of metres thick.

The unit crops out over 14km in length with a width up to 5km (Fig. 1). Near Mt Bocoble, an apparently conformable overlying contact is exposed with limestone (with pentamerid brachiopods and halysitid corals), breccia (limestone clasts in a sandy matrix), conglomerate and shale which resemble, from the fauna and lithology, parts of both the Willow Glen Formation and Millsville Formation. To the southeast of Mt Bocoble, this contact is poorly exposed and the ?overlying rocks are discontinuous unfossiliferous limestone beds.

Lithologies

The Toolamanang Formation is a massive, structureless succession of fine- to coarse-grained arenite with common black mud horizons and sporadic basaltic out-crops. The main rock types consist of dacitic detritus as lithic arkose and feldspathic litharenite; with common very fine ash size rocks and fine-grained breccia. The rocks are texturally similar, being very poorly sorted with angular plagioclase (albite), less common quartz and rare hornblende fragments, up to 3mm across, and a highly variable content of dacite groundmass clasts ranging from several mm to 3cm across. Clasts are tightly packed, with a recrystallized matrix of fine dacitic detritus. Lithological variation in the succession, in which no sequence or marker horizons could be established, is minor and involves rapidly varying grain sizes. Basaltic blocks, petrographically and chemically similar to basaltic rocks in the Cudgegong Volcanics (Pemberton and Offler, 1985) occur throughout the unit, varying in size from tens of centimetres up to 3m across.

The best exposures occur in several cuttings on the new Cudgegong-Mudgee road (GR 631661 to GR 618681) and their associated drill cores. They are dominated by fine- to coarse-grained arenite with massive black mud (fine-grained dacitic ash) beds, from several cm to 1m thick. The bases of the sandy horizons show loading and slumping of the sand squeezed and injected into the mud whereas the tops are generally flat and sharp. Several of the basal zones, which vary from a few cm to 1m thick, have a dis-oriented fabric of irregularly-shaped sandy masses representing intensely churned and squeezed sand within the mud layers. Fine-grained breccia patches (with randomly-aligned arenite and black mud clasts) and angular and rounded basaltic blocks are common.

Both the cuttings and the cores show: firstly, that the basaltic material is fragmental, varying greatly in size and that this material has been deposited in the muddy and sandy detritus; and secondly, that the grain size of, and thickness of the units within, the dacitic detritus varies rapidly, indicating multiple depositional episodes, and that contacts between units are sharp and show evidence of loading and slumping.

Age and Correlation

No fauna has, as yet, been found in the Toolamanang Formation. The unit is considered Late Silurian on the basis of the Wenlockian to Ludlovian age of the conformably underlying Willow Glen Formation and the preliminary dating of the fauna from ?overlying limestone near Mt Bocoble as Late Silurian.

Lithologies in the formation consist principally of volcanic detritus of similar composition to dacite lava, the dominant rock type in the Windamere Volcanics. Together with similarities in age and underlying and overlying formations, the

Toolamangang Formation is considered a lateral equivalent, and fragmental version, of the Windamere Volcanics.

Correlatives of the Windamere Volcanics, the Bells Creek Volcanics (Packham, 1968) and the Mullions Range Volcanics on the Molong High (Hilyard, 1981); both contain a high proportion of fragmental rhyolitic and dacitic material as does the Toolamanang Formation.

Structure

Rare bedding data display the regional southeast strike with steep southwest dips. R. Offler (pers. comm.), in a study to the northeast of the new Cudgegong-Mudgee road (Fig. 1), confirmed the southwest-dipping trend yet he noted dip reversals within and between outcrops indicating small scale southeast-plunging folds.

There has been no attempt to compile a representative section due to the lack of established sequence, the unknown internal structure and the poorly known southern portion of the formation. If the apparently overlying strata are Millsville Formation equivalents, the formation may be simply dipping to the southwest and the 5km outcrop width produces a thickness of approximately 3.5km. Alternatively, the outcrop pattern near Cudgegong suggests a synclinal structure (Pemberton, 1980a) with an upright sequence on the eastern limb and, if the ?overlying rocks are Willow Glen Formation equivalents, the larger scale structure may be a northwest-plunging syncline with the southwest limb overturned. As a consequence the unit thickness may be nearer 1.5 to 2km.

Environment of Deposition

The pervasive arenite of the Toolamanang Formation consists of angular, poorly sorted, ash- to fine lapilli-sized dacitic detritus in massive structureless outcrops and suggests deposition as an unsorted crystal and lithic ash formed from dense, gravity-driven, volcaniclastic flows (Cas and Wright, 1987).

The black muddy rocks are composed of very fine-grained dacitic detritus and vary from massive bodies to intensely-churned zones formed by slumping and loading of the overlying sands. The rocks suggest deposition as mud flows associated with the coarser ash-flow events. The black mud clasts in the breccia indicate transport of partially lithified mud.

The basaltic rocks are considered part of the Cudgegong Volcanics basement which has been included in the debris flows by erosion, or possibly explosive ejection, from the flanks of the Late Silurian volcano and subsequently transported, with minor reworking, prior to the dumping of the load into the sandy and muddy strata.

There are no direct indicators of a subaqueous or subaerial environment for the debris flows, although the underlying, tentatively overlying and laterally equivalent units exhibit shallow marine to emergent characteristics. The slumping so typical of the arenaceous rocks can occur on fairly gentle slopes and this suggests the detritus was deposited into slightly deeper water conditions than that of the northwest source.

It has been previously implied that the processes which initiated the debris flows of the Toolamanang Formation may have provided the mechanism to erupt the thick Windamere Volcanics lava body. The emplacement of similar silicic bodies produces a variable yet significant volume of pyroclastic material, which acts as the explosive degassing mechanism preceding thick lava growth (Heiken and Wohletz, 1987; Scott, 1987). There is no evidence of explosive activity preserved in the Toolamanang Formation; however, the variable grain size within the thick flow succession clearly represents a large number of flow episodes. It remains to be proven that the episodes were explosively initiated thus providing the volatile release necessary to allow the Windamere Volcanics emplacement.

MILLSVILLE FORMATION (Powis 1975)

Offenberg *et al.* (1971) included these rocks in the Siluro-Devonian Gulgamree Beds. However, Powis (1975) recognized their Late Silurian age and demonstrated mappable differences from the nearby Early Devonian sequences. He proposed the name Millsville Beds, after the nearby property. Further mapping by Pemberton (1980b, and more recently) has confirmed Powis' ideas and herein the sequence is formally named the Millsville Formation.

Stratigraphic Relationships

There are two main outcrop areas of the Millsville Formation here described as the southeast and northwest exposures (Fig. 10; location from Figs 1 and 8).

The major rock type is breccia with dominantly limestone and minor dacite and rhyolite clasts in a dacitic matrix. Subordinate rocks include: limestone (biosparite and biomicrite); a gradational sequence of shale, arenite and fine-grained conglomerate of calcareous and dacitic detritus; and well-defined dacitic conglomerate and breccia horizons (Table 5). In addition, thick rhyolite lava, with rare breccia, occurs at the top of the formation.

In both areas, the formation conformably overlies dacite of the Windamere Volcanics, with gradational contacts recognized by an increase in fragmental dacitic material and the appearance of limestone lenses and detritus. However, the basal rocks in certain localities in the northwest area are discontinuous (up to 100m long) dacitic conglomerate lenses up to 10m thick (Fig. 10).

The pervasive breccia is present throughout the formation with little lithological variation. Limestone horizons vary from rare thin lenses, from several cm to 1m thick, to several prominent *in situ* bodies up to 300m long with thickness to 100m (Fig. 10). Thinly-bedded fossiliferous shale, and flat-bedded arenite to fine-grained conglomerate occur as discrete horizons or as gradational lenses within the breccia succession.

The northwest area and certain localities in the southeast area are conformably overlain by a persistent rhyolitic succession. The rhyolite and remaining Millsville Formation are disconformably overlain by the Early Devonian Mullamuddy Formation (Fig. 10).

In general, the formation is typified by rapid facies change. Marker horizons are few and include the basal dacitic conglomerate in the northwest area and a prominent 10 to 15m thick dacite breccia horizon, outcropping for over 1.5km length, towards the middle of the southeast area sequence (Fig. 10).

Fauna, Age and Correlation

Powis (1975) reported four fossil localities (Fig. 10), in limestone and shale, to which he assigned a Silurian age. His faunal lists included: limestone — *Phaulactis*, heliolitids, favositids, stromatoporoids, and pentamerid brachiopods; shale — *Halysites* cf. *bellensis*, *Encrinurus*, *Rhizophyllum*, *Eospirifer*, *Leptaena* together with orthid, atrypid and rhynchonellid brachiopods. Pickett (1982a) noted *Kirkidium*, *Thamnopora*, *Amphipora*, and *?Propora*, together with rare conodonts (not age-diagnostic), within the prominent limestone of the northwest area. The fauna is clearly Silurian and the recognition of faunal similarities with the Willow Glen Formation, together with the relationship of the formation to the underlying Windamere Volcanics and the overlying Lochkovian to

Pragian Mullamuddy Formation, indicates a Late Silurian (Wenlockian to Ludlovian) age for the Millsville Formation.

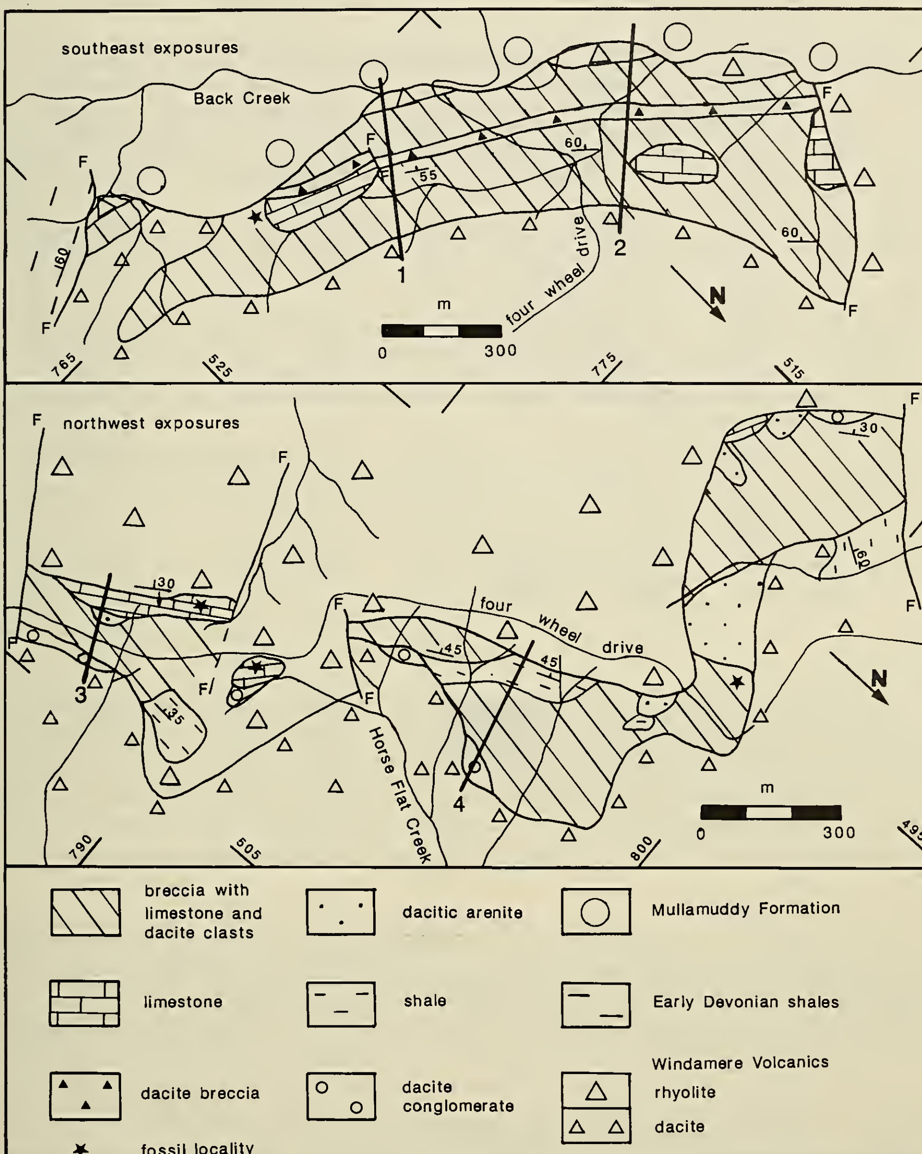

Fig. 10. Geology of the two outcrop areas of the Millsville Formation.

The Ordovician-Silurian sequences at Cudgegong and Sofala are similar; however, Windamere Volcanics-Toolamanang Formation equivalents in the Sofala area are conformably overlain by deep water rocks of the Hill End Trough sequence (Packham, 1968). However, in the Cudgegong-Mudgee district, Late Silurian rocks overlying silicic volcanic sequences (the Millsville Formation) are deposited in a shallow marine environment.

TABLE 5

Petrography of the rock types in the Millsville Formation

breccia	Grey to pink, very fine sand to boulder size (1m), very poorly sorted, immature. Angular to subangular (larger clasts more rounded) dominantly limestone (poorly washed biosparite with limy mud fraction) clasts, from 5cm to 1m across, with subordinate dacite (lava and arenite), rhyolite lava, shale, and siliceous clasts to 10cm across. Matrix supported; matrix consists of fine- to coarse-grained arenaceous dacitic and calcareous detritus.
limestone	Grey, cream to red; poorly washed biosparite (rich in corals, brachiopods and stromatoporoids) with limy mud horizons; sparse to packed biomicrite; and calcirudite patches (Powis, 1975).
dacitic conglomerate	Grey, fine sand to boulder size (0.5m), very poorly sorted. Rounded to angular dacite lava clasts, from 10cm to 30cm across, with rare boulders to 0.5m. Clast-supported with minor dacitic matrix. No clast alignment. Boulder horizon in southeast exposures similar texture yet clasts angular and coarser.
dacitic breccia	Grey to brown, fine sand to boulder size (0.5m), very poorly sorted, immature. Angular dacite (lava and arenite) clasts from several cm to 20cm across, rarely to 0.5m; with common limestone clasts to several cm across. Matrix supported; matrix of dacitic detritus.

Structure

There is no evidence of folding within the formation. Limited bedding data indicate a consistently southwest-dipping unit up to 220m thick. Further, geopetals (brachiopod and stromatoporoid orientations) in the limestone indicate upright horizons. Consequently four representative sections (Fig. 11, locations from Fig. 10) have been produced for areas of best exposure. Horizons within each outcrop area may be crudely correlated; however, it is not possible to correlate between outcrop areas.

Environment of Deposition

The appearance of limestone and shale horizons at the top of the Windamere Volcanics signals the start of volcanic quiescence in a shallow marine environment. The basal dacitic conglomerate does not show features indicative of a fluvial channel origin and the very poorly sorted, clast-supported lenses are likely to represent beach deposits.

The autochthonous limestone bodies contain a distinctive pentamerid brachiopod-coral fauna typical of rough water limestone bank or mound communities (Boucot, 1975) on a shallow marine shelf. The shale horizons (*in situ* coral growth and a low degree of brachiopod and trilobite fragmentation) formed during quiet water periods and together with the limestone represent bank to lagoonal deposition.

The pervasive breccia suggests collapse of the limestone banks, possibly due to storm activity, and the subsequent dumping of this material into dacitic detritus in slightly deeper water.

The Millsville Formation represents deposition on a shallow marine shelf where initially extensive bank to lagoonal areas, with minor beach deposits, were subsequently affected by limestone bank collapse into slightly deeper water.

Persistent volcanism was then resumed as thick rhyolite masses conformably overlie the shelf deposits, especially in the northwest area.

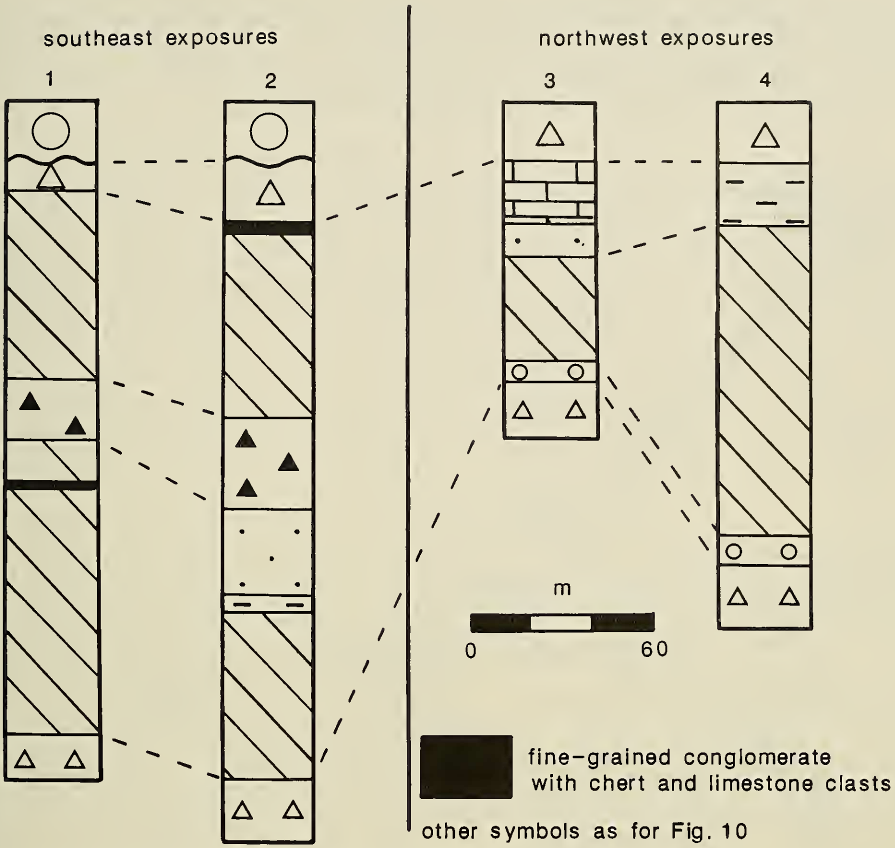

Fig. 11. Representative sections through the Millsville Formation.

Discussion

Nature of the Contacts with the Overlying Strata

Wright (1966) recognized that the Ordovician-Silurian sequences, described in this paper, separated two belts of Devonian rocks — the Queens Pinch Belt and the Mt Frome to Kandos Belt (Fig. 12).

Queens Pinch Belt (Carne and Jones 1919)

The belt consists of a number of fault-bounded slices of Early Devonian shelf and turbidite facies rocks deposited on the western margin of the Capertee High (Wright, pers. comm. and in Strusz, 1972). Contacts with the Ordovician-Silurian rocks are mainly faulted, particularly in the Limestone Creek area; however, disconformable contacts have been identified between the oldest unit in the Queens Pinch Belt, the Lochkovian to Pragian Mullamuddy Formation, and the Wenlockian to Ludlovian units — the Windamere Volcanics near Mt Margaret (GR 545757) and the Millsville Formation along Back Creek (GR 520765).

Immediately north of Mt Margaret, the top of the Late Silurian rhyolite has been reworked and at the base of the Mullamuddy Formation, a black shale, up to 1.5m thick, containing abundant rhyolite clasts grades up to an *in situ* limestone horizon. Near Back Creek, the base of the Mullamuddy Formation has eroded deeply into the Millsville Formation as the contact cuts through rhyolite and breccia successions as well as the prominent dacite breccia horizon (Fig. 10). Here, the Mullamuddy Formation is a breccia of unsorted rhyolite and limestone cobbles and boulders.

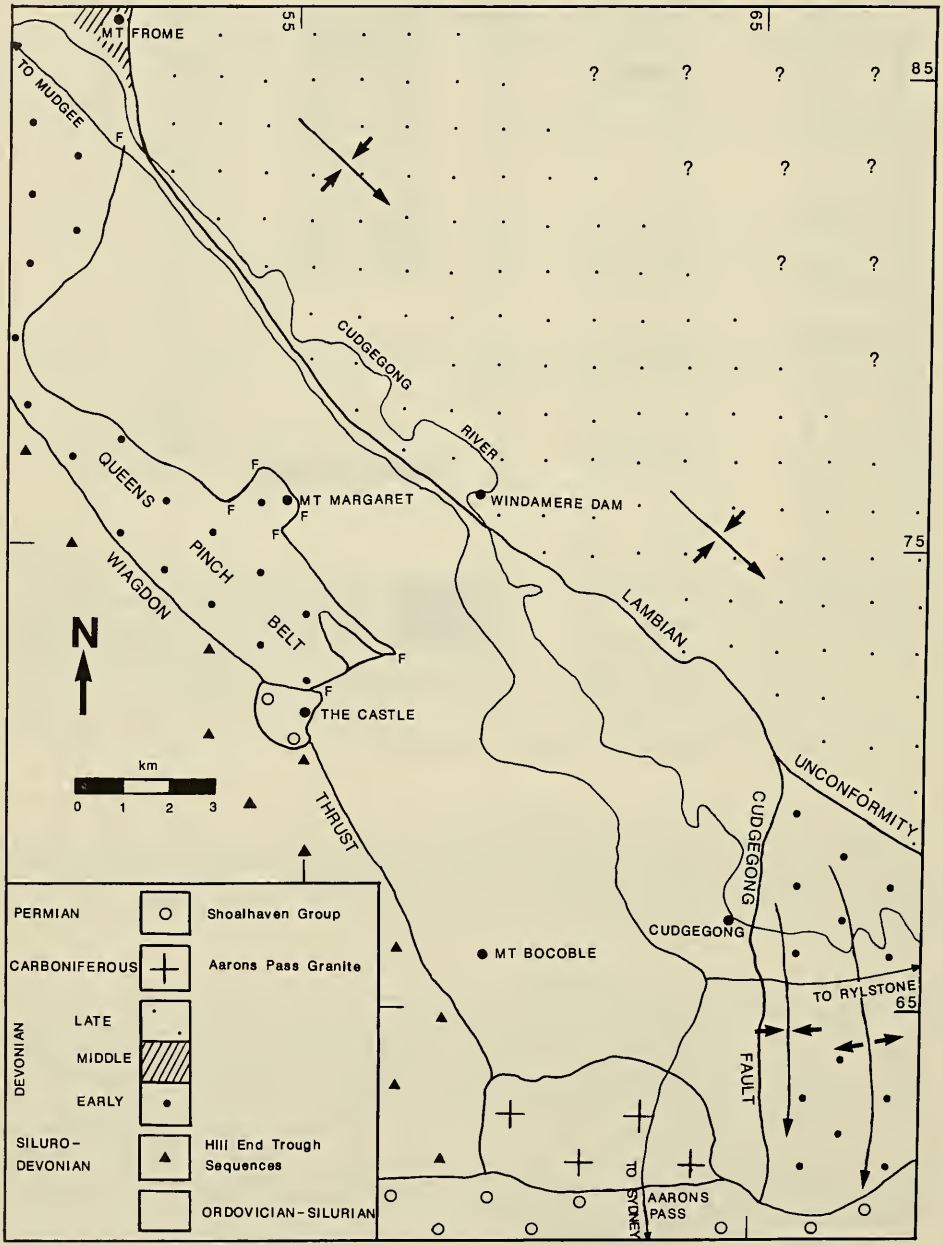

Fig. 12. Post-Silurian geology of the Cudgegong-Mudgee district.

Mt Frome to Kandos Belt

The belt comprises a thick sequence of Late Devonian fluviatile and shallow marine successions (Wright, 1966) together with Early Devonian shallow marine sediments and volcanics in the Cudgegong-Rylstone district (Pemberton, 1977; Campbell, 1980; Millsteed, 1985; Cook, 1988; Colquhoun, 1989).

Cudgegong Fault (Game 1935)

Game (1935) proposed a large scale strike-slip fault (the Cudgegong Fault) separated Ordovician-Silurian and Devonian sequences along the Cudgegong River valley and to the southeast of Cudgegong. Pemberton (1980a) and Millsteed (1985) have confirmed a faulted contact between Late Silurian and Early Devonian strata from the Permian plateau to the headwaters of Ironstone Creek (Figs 5 and 12). Evidence for the Cudgegong Fault in this area includes the truncation of folded Early Devonian units and several members of the Late Silurian sequence. The fault plane is marked by a thick linear ferruginous zone and a restricted fault breccia. In addition, C. L. Fergusson (pers. comm., 1987) noted the development of a prominent zone of tectonic melange in a road cutting (GR 652653) on the Cudgegong-Rylstone road along the line of the fault.

Lambian Unconformity (Powell and Edgecombe 1978)

A low angle discordance between the Late Devonian Lambie Group and a variety of older rocks, the Lambian Unconformity, has been recorded from numerous localities in the northeast Lachlan Fold Belt. In the Mudgee district (Fig. 12), the basal Late Devonian unit, the Buckaroo Conglomerate of Wright (1966), crops out continuously from Mt Frome to the Carwell Creek district.

Near Mt Frome, Powell and Edgecombe (1978) record an angular discordance of 5° to 24° where the Buckaroo Conglomerate overlies the latest Early to early Middle Devonian sequence (Garratt and Wright, 1988). To the southeast, the contact is covered by the Cudgegong River floodplain. An exception exists near the Windamere Dam spillway where the Lambian Unconformity can be recognized along the road from the spillway to the observation deck. Here the top of the Windamere Volcanics is represented by 5m of intensely weathered dacite in sharp contact with the northeast-dipping Buckaroo Conglomerate. Gross (1982) noted a discordance of up to 28° with the Buckaroo Conglomerate.

To the south of Cudgegong, the Ordovician-Silurian strata are intruded by the Middle Carboniferous (320 Ma, Vickary, 1983) Aarons Pass Granite, a massive biotite granite/adamellite stock of 10km diameter. The strata are unconformably overlain by thin flat-lying veneers of Sydney Basin outliers at Aarons Pass, Mt Margaret, the Castle and Mt Bocoble (Fig. 12). At these localities, polymictic conglomerate and pebbly litharenite represent the basal unit in the Snapper Point Formation of the Shoalhaven Group (Bembrick, 1983).

Geological History of the Cudgegong-Mudgee District

Ordovician

The oldest rocks in the Cudgegong-Mudgee district, the Late Ordovician (Gisbornian) Cudgegong Volcanics consist of basaltic and andesitic arenite, breccia and rare lava associated with volcaniclastic debris flows on the flanks of submarine volcanoes with fringing shallow marine areas. These rocks are correlated with the upper parts of the Sofala Volcanics in the Sofala district. Other strata tentatively assigned an Ordovician age on the northern Capertee High are flysch-like sequences to the northwest (Lue Beds, Offenberg *et al.*, 1971) and west of Rylstone (Colquhoun, 1989). The

Cudgegong Volcanics-Sofala Volcanics association constitutes a Late Ordovician volcanic arc providing a number of basaltic and andesitic eruptive centres with fringing shallow water environments, with possibly deeper water flysch conditions to the east.

Silurian

The Cudgegong Volcanics are unconformably overlain by Wenlockian to Ludlovian sequences. Similar contacts occur at Sofala and possibly west of Rylstone, and the absence of Llandoverian units confirms that deformation of the volcanic arc continued through the Benambran/Quidongan event (Crook *et al.*, 1973; Cas, 1983).

There is a thick and persistent succession of Wenlockian to Ludlovian shallow marine to possibly emergent units exposed in the Cudgegong-Mudgee district. The lowermost unit, the Willow Glen Formation (conglomerate, pebbly arenite and arenite; fossiliferous shale and limestone) was deposited in a southeast-facing coastal environment which included a fluvial channel zone; subtidal to supratidal flats, affected by a series of transgressive-regressive cycles including common incision by fluvial channels; and more open marine shelf conditions.

The conformably overlying Windamere Volcanics-Toolamanang Formation eruptive episode produced up to 1500m of undifferentiated dacite lava and breccia (the Windamere Volcanics) possibly emplaced as a thick lava dome; and between 2 and 3km of fine- to coarse-grained dacitic detritus with common fragmental basaltic blocks (the Toolamanang Formation). The latter unit was produced by dense, gravity-driven volcaniclastic ash- and mud-flows which incorporated eroded basement material. This was followed by a period of volcanic quiescence represented by the Millsville Formation (up to 220m of dominantly limestone with dacitic and rhyolitic detritus) deposited on a shallow marine shelf.

Late Silurian shallow marine sediments with minor dacite/rhyolite lava and fragmental rocks also occur to the north of Mudgee (Armstrong, 1983), west of Rylstone (Colquhoun, 1989) and tentatively northwest of Rylstone (Offenberg *et al.*, 1971). In the Sofala district, equivalents of the Willow Glen Formation (the Tanwarra Shale) and the Windamere Volcanics-Toolamanang Formation (the Bells Creek Volcanics) are known (Packham, 1968); however, they are far more restricted in extent and thickness than on the northern Capertee High. There is no Millsville Formation equivalent in the Sofala district as the shallow marine rocks are conformably overlain by the deep water Hill End Trough sequence.

Post-Silurian

Contacts with the Early Devonian strata are either faulted or disconformable, the latter representing the effects of the Bowning deformational event (Cas, 1983) on the northern Capertee High.

During the Early and part of the Middle Devonian, the deposition of shallow water to emergent, richly fossiliferous sediments with silicic volcanic outpourings continued on the northern Capertee High (Wright, 1966, 1967, 1981); however, the Queens Pinch Belt consists of both shallow and deep water strata at the western margin of the Capertee High, adjacent to the deep water Hill End Trough. The marked facies change to Late Devonian fluviatile conditions is preceded by deformation resulting in the Lambian Unconformity. Fluviatile conditions, with an increasing shallow marine component, continued possibly into the Early Carboniferous when the effects of the cratonizing Kanimblan deformational event (Cas, 1983) produced folding of the Late Devonian and older rocks, and emplacement of the Middle Carboniferous Aarons Pass Granite.

Peneplanation of much of the Cudgegong-Mudgee district took place before the

Early Permian where the thin, flat-lying remnants of the basal Snapper Point Formation of the Shoalhaven Group represent a sandy transgressive shoreline, at the western margin of the Sydney Basin.

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APPENDIX

Faunal Lists for the Willow Glen Formation

Locality Details	Author (Source)	Fauna Recorded and Age
Locality 1 GR 618725; known locally as Woolleys Flat	**Pickett** (1982a)	corals: *Syringopora, Halysites orthopteroides, Desmidopora multitabulata, Pycnostylus scalariformis* brachiopods: pentamerids conodonts: *Panderodus, Ozarkodina ranuliformis, Distomodus, 'Ozarkodina' media, 'Neoprioniodus'* cf. *bicurvatus* age: Wenlockian to Ludlovian
	Strusz (pers. comm., 1984)	brachiopods: *Spirinella, Aegiria* cf. *norvegica, ?Howellella, Coelospira, Salopina, Stropheodontacea* trilobites: *Encrinurus mitchelli*, proetacean, *?Staurocephalus struszi* (cheek only) crinoids: *Pisocrinus* age: Late Wenlockian to Early Ludlovian
Locality 2 GR 642692 to GR 648687; area just west of Ironstone Creek	**Pickett** (1982a)	corals: *Favosites, Heliolites, Tryplasma, Alveolites, Thamnopora* stromatoporoids: *Amphipora* brachiopods: *Kirkidium* conodonts: *'Ligonodina', '?Lonchodina', Panderodus, Ozarkodina ranuliformis* age: Wenlockian to Ludlovian
	Strusz (pers. comm., 1984)	brachiopods: *Spirinella, ?Howellella, Coelospira cavata, Salopina ?mediocostata, Morinorhyncus oepiki, Maoristrophia, Leptostrophia* trilobites: *Encrinurus mitchelli*, proetacean corals: *Entelophyllum* age: Late Wenlockian to Early Ludlovian
Locality 3 GR 563740; just south and west of four wheel drive track north of Limestone Creek	**Pickett** (1982a)	corals: *Phaulactis, Tryplasma, Alveolites* stromatoporoids: *Amphipora* brachiopods: *Kirkidium* conodonts: *Ozarkodina ranuliformis* age: Wenlockian to Ludlovian
	Strusz (pers. comm., 1984)	brachiopods: *Aegiria, Coelospira, ?Howellella* trilobites: *Encrinurus mitchelli* corals: *Halysites, Tryplasma* age: Late Wenlockian to Early Ludlovian

Locality Details	Author (Source)	Fauna Recorded and Age
Locality 4 GR 600732; just west of Horseshoe Bend on Cudgegong River	**Strusz** (pers.comm., 1984)	corals: *Cystiphyllum, Tryplasma ?lonsdalei, Phaulactis shearsbyi, Syringopora, Palaeophyllum*
	Pemberton (additional specimens identified by A. J. Wright)	corals: *Halysites, Favosites, Heliolites* age: probably Wenlockian to Ludlovian
Locality 5 GR 653637; in the upper limestone bed just west of track along Oakey Creek, southeast of Cudgegong	**Pickett** (1982a)	corals: *Propora, Tryplasma, Favosites, Phaulactis* brachiopods: *Kirkidium* age: Wenlockian to Ludlovian
Locality 6 GR 560761; approx. 2km west of 'Windamere Village'	**Pemberton (identified by A. J. Wright)**	corals: *Tryplasma, Thamnopora, Phaulactis, Favosites, Halysites* brachiopods: pentamerids age: Late Silurian
Locality 7 GR 612698; just north of new Cudgegong-Mudgee road, approx. 3km east of Limestone Creek	**Pemberton (identified by A. J. Wright)**	corals: *Halysites, Favosites* brachiopods: pentamerids age: Late Silurian
Locality 8 GR 562717; approx. 1km south of Limestone Creek road, at east margin of southwest area	**Pickett** (1982a)	conodonts: *'Ligonodina', 'Spathognathodus', 'Hindeodella', 'Ozarkodina' denckmanni, Distomodus, Panderodus, Ozarkodina* cf. *remscheidensis, Delotaxis* cf. *elegans, 'Belodella' triangularis* age: very Early Devonian
	Pemberton (identified by A. J. Wright)	corals: *Halysites, Favosites, Heliolites* brachiopods: pentamerids age: Late Silurian
Locality 9 GR 528796; approx. 0.5km southeast of Appletree Flat, northwest area	**Pemberton (identified by A. J. Wright)**	corals: *Heliolites* brachiopods: pentamerids age: Late Silurian